Effective theories across the frontiers

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Theory panel, 2 August 2013

- *theory is not programmable. Progress often comes from exploiting connections between fields/frontiers/disciplines*

  subtext: intensity frontier theory for its own sake, but also influences broader theory

- *theorists must demand error bars from experimenters, who in turn must demand improvements from theory*

- *nucleon physics is not nuclear physics (not that there's anything wrong with that)*

- *experimental data drives theory. Demand for precision and quantitative predictions leads to new theoretical developments that underpin next generation experiments.*

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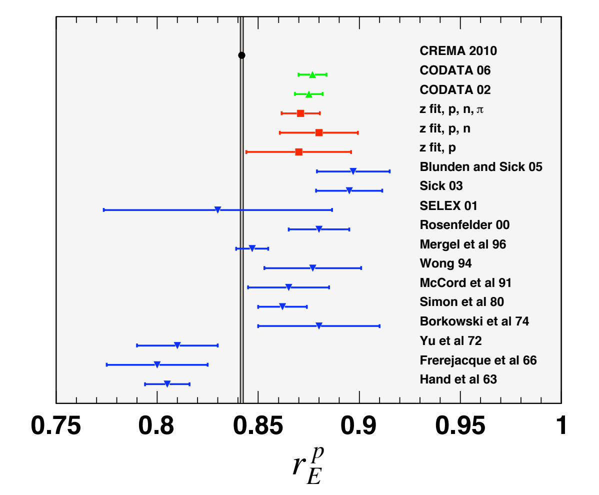
e.g. : atoms



what's at stake:

- ~7σ shift in Rydberg + discarding of decades of scattering and spectroscopic data ?
- large radiative corrections to leading proton structure ?
- experimental error ?
- something "new" ?

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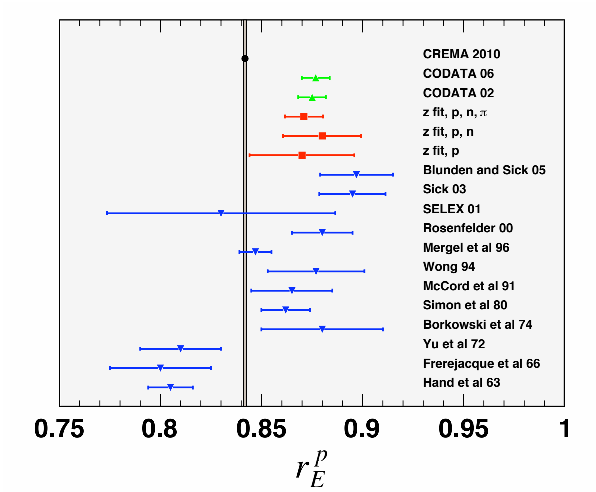

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heavy particle effective theory (NRQED of composite particles)

Lorentz invariance in heavy particle effective theories: *[Heinonen, Solon, RJH, 1208.0601]*

- chiral lagrangian = nonlinear realization of chiral symmetries
- HPEFT = nonlinear (induced) representation of Lorentz symmetry (noncommutative manifold)
- contradicts ~20 year old ansatz of reparameterization invariance, underlying HQET, etc.

would not have asked these questions if not driven by data

many consequences and applications:

- feedback into atomic physics (model independent analysis of rad.corr. to nuclear structure, cf. Friar 1979) *[Lee, Paz, Solon, RJH, 1212.4508]*
- nucleon properties, e.g. polarizabilities from lattice QCD, $\alpha_{\text{static, lattice}} \neq \alpha_{\text{scattering, PDG}}$
- BSM particles, e.g. heavy WIMPs

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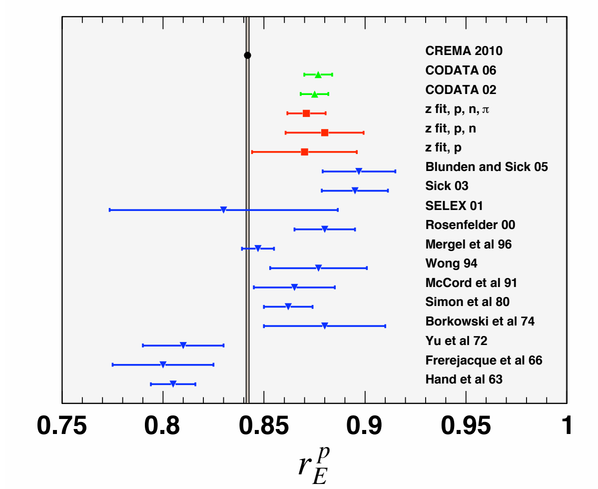

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heavy WIMP effective theory

- WIMPs plausibly heavy compared to m_W, m_Z (maybe not extremely small, cf. m_h/m_t)
- analog of heavy-quark spin-flavor symmetry:
- BSM particles, e.g. heavy WIMPs

- hydrogen spectroscopy

$$E_n(H) = -\frac{1}{2} m_e \alpha^2 + \dots$$

- heavy meson transitions

$$F^{B\to D}(v' = v) = 1 + \dots$$

- DM interactions

$$\sigma(\chi N \to \chi N) = ?$$

(self-conjugate, spin-independent case)

$$\mathcal{L}_{\chi,SM} = \chi^* \chi \Big\{ \sum_q c_{1q}^{(0)} O_{1q}^{(0)} + c_{1q}^{(2)} v_\mu v_\nu O_{1q}^{(2)\mu\nu} + c_2^{(0)} O_2^{(0)} + c_2^{(2)} v_\mu v_\nu O_2^{(2)\mu\nu} + \dots \Big\}$$

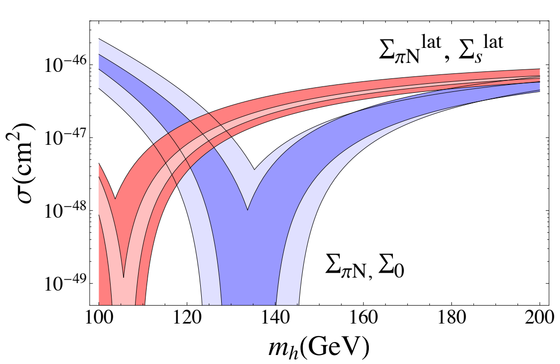
$$O_{1q}^{(0)} = m_q \bar{q} q \,, \qquad O_2^{(0)} = (G^A_{\mu\nu})^2 \,,$$

$$O_{1q}^{(2)\mu\nu} = \bar{q} \left(\gamma^{\{\mu} i D^{\nu\}} - \frac{1}{d} g^{\mu\nu} i \not{D} \right) q \,, \qquad O_2^{(2)\mu\nu} = -G^{A\mu\lambda} G^{A\nu}{}_\lambda + \frac{1}{d} g^{\mu\nu} (G^A_{\alpha\beta})^2 \,.$$

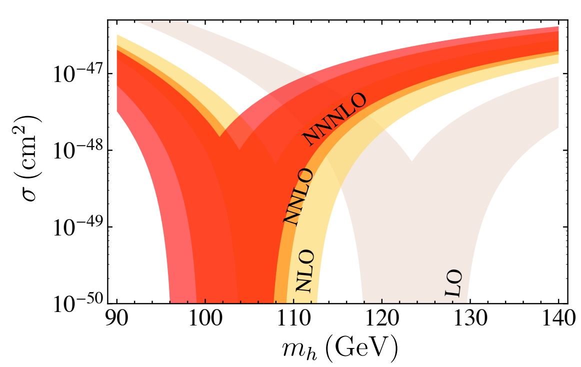
→ complete results for the leading weak-scale matching coefficients

$$c_i(m_W, M) = c_i^{(0)} + c_i^{(1)} \frac{m_W}{M} + \dots$$

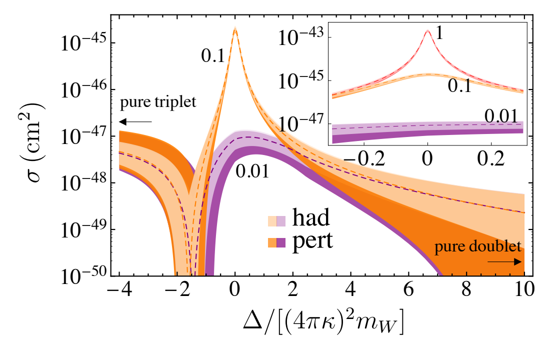
hadronic uncertainties matter

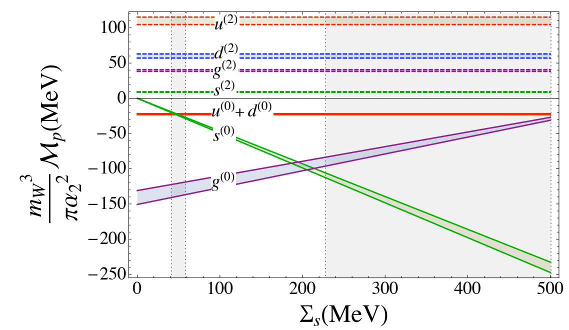


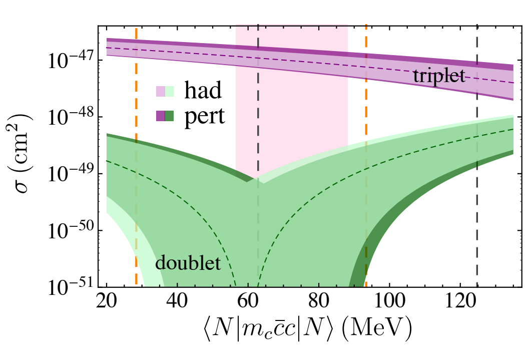
subleading perturbative QCD matters



mixing with massive states treated similarly







[Solon, RJH 1111.0016]

→absolute predictions, with error bars

Exciting, challenging time for dark matter searches:

knowledge of SM parameters and hadronic matrix elements

⇒ absolute predictions for scattering cross sections of WIMP dark matter

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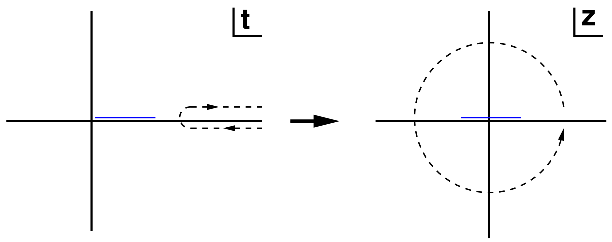
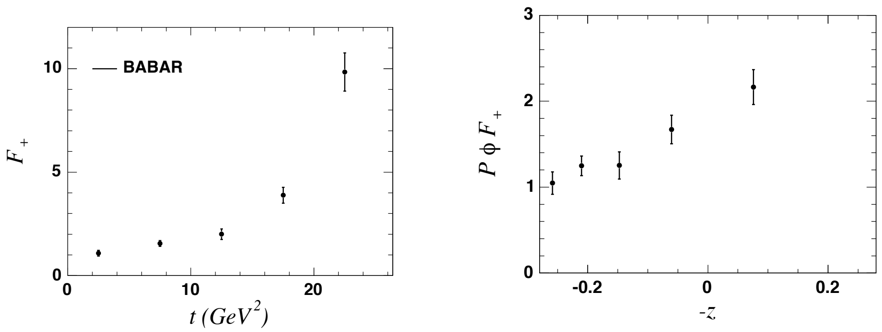
heavy meson processes

theory developments

analyticity





lattice QCD

SCET, HQET, NRQCD

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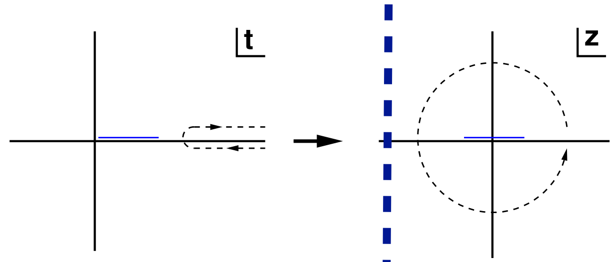
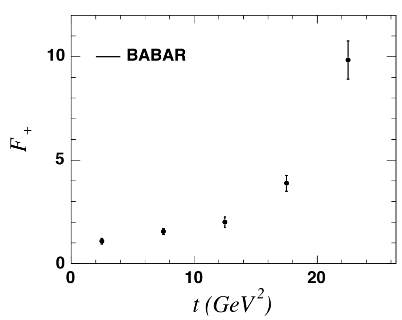
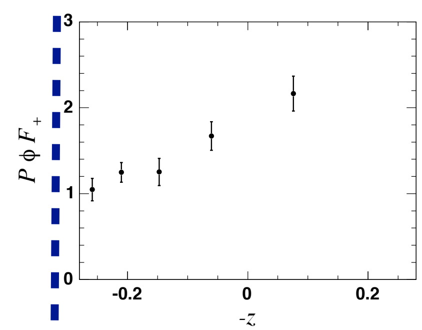




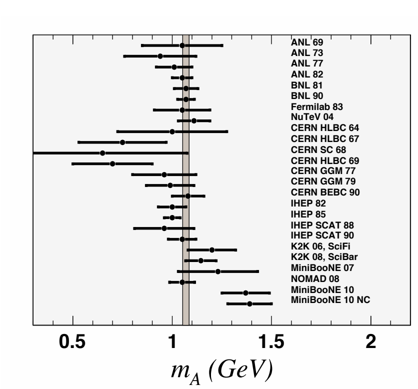


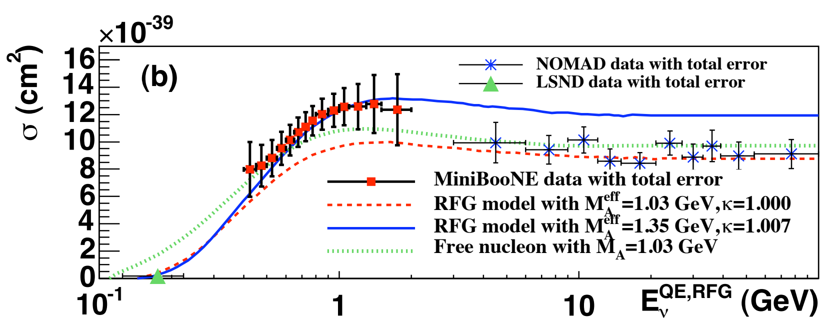
muon g-2, ...

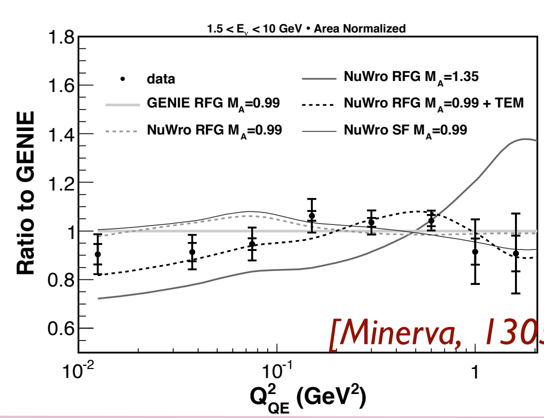
collider QCD, ...

new applications

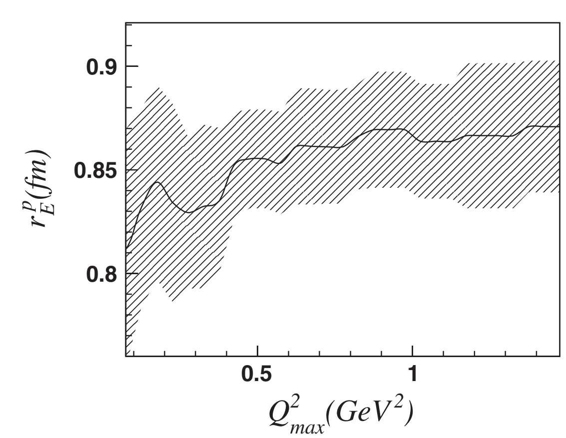
model independent description of lepton-nucleon scattering



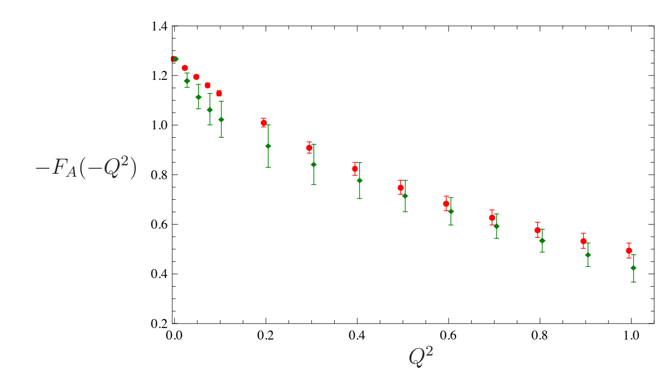




[Minerva, 1305.2243]



[Paz, RJH, 1008.4619]

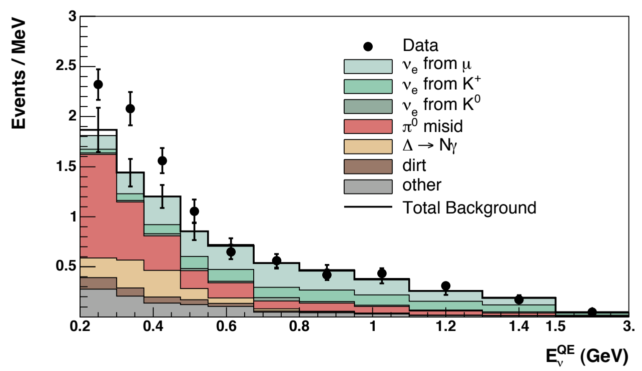


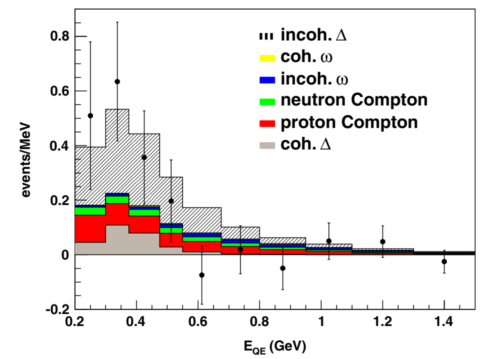
[Bhattacharya, Paz, RJH, 1108.0423]

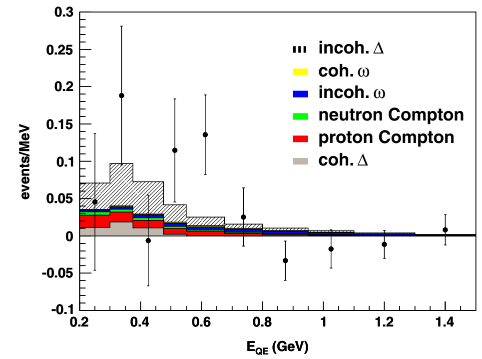
problems

solutions

- *theorists must demand error bars from experimenters, who in turn must demand improved theory*







neutrino-nucleus cross sections notoriously difficult. E.g., MiniBooNE excess: deviation from MC in never-measured single-photon production, or new physics ?

What is the uncertainty ? Is 15% reasonable ? Recall ~40% uncertainty on basic CCQE

Event generators:
- typically RFG model at nuclear level (now receiving some attention) *[Smith and Moniz 1972]*
- antiquated nucleon-level assumptions *[Llewellyn Smith 1972]*

Essential for next generation experiments to do better with both nucleon-level inputs and nuclear modeling

- *nucleon, nuclear and hadronic physics, including radiative corrections, essential to "Intensity frontier" experiments*
  - neutrinos, g-2, edm, mu-e, proton decay, n-nbar oscillation, ...
  - should be the domain of HEP to study the entire problem. Can't outsource.

- *experimental data drives theory. Demand for precision and quantitative predictions leads to new theoretical developments that motivate and underpin new experiments.*